NOAA Technical Report NESDIS 45

FINAL REPORT ON THE MODULATION AND EMC CONSIDERATIONS FOR THE HRPT TRANSMISSION SYSTEM IN THE POST NOAA-M POLAR ORBITING SATELLITE ERA

Washington, D.C.
June 1989

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL REPORTS
National Environmental Satellite, Data, and Information Service

The National Environmental Satellite, Data, and Information Service (NESDIS) manages the Nation's civil Earth-observing satellite systems, as well as global national data bases for meteorology, oceanography, geophysics, and solar-terrestrial sciences. From these sources, it develops and disseminates environmental data and information products critical to the protection of life and property, national defense, the national economy, energy development and distribution, global food supplies, and the development of natural resources.

Publication in the NOAA Technical Report series does not preclude later publication in scientific journals in expanded or modified form. The NESDIS series of NOAA Technical Reports is a continuation of the former NESS and EDIS series of NOAA Technical Reports and the NESC and EDS series of Environmental Science Services Administration (ESSA) Technical Reports.

These reports are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161 (prices on request for paper copies or microfiche, please refer to PB number when ordering) or by contacting Nancy Everson, NOAA/NESDIS, 5200 Auth Road, Washington, DC 20233 (when extra copies are available). A partial listing of more recent reports appear below:

NESDIS SERIES

NESDIS 1 Satellite Observations on Variations in Southern Hemisphere Snow Cover. Kenneth F. Dewey and Richard Heim, Jr., June 1983. (PB83 252908)

NESDIS 2 NODC 1 An Environmental Guide to Ocean Thermal Energy Conversion (OTEC) Operations in the Gulf of Mexico. National Oceanographic Data Center, June 1983. (PB84 115146)

NESDIS 3 Determination of the Planetary Radiation Budget from TIROS-N Satellites. Arnold Gruber, Irwin Ruff and Charles Earnest, August 1983. (PB84 100916)

NESDIS 4 Some Applications of Satellite Radiation Observations to Climate Studies. T.S. Chen, George Ohring and Haim Ganot, September 1983. (PB84 108109)

NESDIS 5 A Statistical Technique for Forecasting Severe Weather from Vertical Soundings by Satellite and Radiosonde. David L. Keller and William L. Smith, June 1983. (PB84 114099)

NESDIS 6 Spatial and Temporal Distribution of Northern Hemisphere Snow Cover. Burt J. Morse and Chester F. Ropelewski (NWS), October 1983. (PB84 118348)

NESDIS 7 Fire Detection Using the NOAA--Series Satellites. Michael Matson, Stanley R. Schneider, Billie Aldridge and Barry Satchwell (NWS), January 1984. (PB84 176890)

NESDIS 8 Monitoring of Long Waves in the Eastern Equatorial Pacific 1981-83 Using Satellite Multi-Channel Sea Surface Temperature Charts. Richard Legeckis and William Pichel, April 1984. (PB84 190487)

NESDIS 9 The NESDIS-SEL Lear Aircraft Instruments and Data Recording System. Gilbert R. Smith, Kenneth O. Hayes, John S. Knoll and Robert S. Koyanagi, June 1984. (PB84 219674)

NESDIS 10 Atlas of Reflectance Patterns for Uniform Earth and Cloud Surfaces (NIMBUS-7 ERB--61 Days). V.R. Taylor and L.L. Stowe,July 1984. (PB85 12440)

NESDIS 11 Tropical Cyclone Intensity Analysis Using Satellite Data. Vernon F. Dvorak, September 1984. PB85 112951)

NESDIS 12 Utilization of the Polar Platform of NASA's Space Station Program for Operational Earth Observations. John H. McElroy and Stanley R. Schneider, September 1984. (PB85 1525027AS)

NESDIS 13 Summary and Analyses of the NOAA N-ROSS/ERS-1 Environmental Data Development Activity. John W. Sherman III, February 1984. (PB85 222743/43)

NESDIS 14 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Activity. John W. Sherman III, February 1985. (PB86 139284 A/S)

NESDIS 15 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Products and Services. Franklin E. Kniskern, February 1985, (PB86 213527/AS)

NOAA Technical Report NESDIS 45

FINAL REPORT ON THE MODULATION AND EMC CONSIDERATIONS FOR THE HRPT TRANSMISSION SYSTEM IN THE POST NOAA-M POLAR ORBITING SATELLITE ERA

Edited by
James C. Fischer
Office of Systems Development
Advanced Systems Division

Work Performed
Under Contract By
Atlantic Research Corporation

Washington, D.C.
June 1989

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

National Oceanic and Atmospheric Administration
William E. Evans, Under Secretary

National Environmental Satellite, Data, and Information Service
Thomas N. Pyke, Jr. Assistant Administrator

FOREWORD

This report was done by Atlantic Research Corporation for the National Environmental Satellite, Data and Information Service (NESDIS). The report is intended to provide information on the design and implementation of possible higher data rate instruments into the High Resolution Picture Transmission (HRPT) and Command and Data Acquisition (CDA) data transmission systems on post NOAA-M satellites which are expected to enter service in the late 1990's. The report presents analyses and recommendations in two general areas: (1) HRPT link power budget and modulation, based primarily on the need to minimize the cost and complexity of modifications to existing user equipment, and (2) potential HRPT and CDA design or operating constraints, based on the need for electromagnetic compatibility with respect to other systems.

The information contained in this document is based on the best estimates available as of May, 1989 of data transmission requirements and preliminary design specifications for the next generation of polar orbiting meteorological sensors and satellites. In the event that requirements or system parameters change from those assumed in this study, it should generally be possible to project the effects of those changes on the calculations and results presented herein. Readers of this report should be aware that system equipment and/or design changes will occur. Managers and manufacturers of HRPT stations and components should not change configurations based upon the assumptions made in this report. As the design of the post NOAA-M system progresses, updates to this report will be issued.

CONTENTS

SECTION 1 - INTRODUCTION

1.1 General Background....................................1-1
1.2 Document Contents.....................................1-1
1.3 Document Use..1-2

SECTION 2 - HRPT USER-BASED LINK DESIGN CONSIDERATIONS

2.1 Introduction..2-1
2.2 Fundamental Requirements..............................2-1

2.2.1 Bandwidth Available for HRPT........................2-2
2.2.2 Bandwidth Considerations for Receivers..............2-2
2.2.3 Power Efficiency....................................2-2

2.3 Candidate Modulation Methods..........................2-4

2.3.1 OQPSK...2-4
2.3.2 UQPSK...2-4

2.4 User-Equipment Tradeoffs Between OQPSK and UQPSK.........2-7

2.4.1 Impact on Receiver System...........................2-7
2.4.2 Impact on Data Processing System....................2-8

2.5 Required Receiver Modifications.......................2-8

2.5.1 I-Channel Reception.................................2-8
2.5.2 Q-Channel Reception.................................2-9

3. ELECTROMAGNETIC COMPATIBILITY OF HRPT DOWNLINKS

3.1 Introduction..3-1
3.2 Interference Considerations...........................3-1

3.2.1 Interference Among POMS.............................3-1
3.2.2 Interference From Post-NOAA-M HRPT to Other Services.............3-4

3.3 Frequency Plans.......................................3-6
3.4 Transmitter Filters...................................3-7

CONTENTS (Cont)

4. ELECTROMAGNETIC COMPATIBILITY OF CDA DOWNLINKS

4.1 Introduction....................4-1
4.2 Baseline CDA Link Power Budget....................4-1
4.3 Design and Implementation Constraints Due to Interference....................4-3

4.3.1 Impact of Interference from Satellites....................4-3
4.3.2 Impact of Interference from Radio-Relay Stations....................4-3
4.3.3 Data Rate Impact....................4-4

APPENDICES

Appendix A - Interference Among Downlinks From POMS at 1700 MHz....................A-1

Appendix B - Analysis of Frequency Sharing With Systems in the Fixed-Satellite Service Operating in the Band 7450-7550 MHz....................B-1

Appendix C - References....................C-1

LIST OF FIGURES

3-1a NOAA-M/predecessor frequency plan....................3-7
3-1b Proposed post-NOAA-M frequency plan..................3-7
3-1c Worst case frequency use during transition...........3-7

LIST OF TABLES

2-1 Reference earth station receiver modules................2-3
2-2 Recommended receiver bandwidths.........................2-3
2-3 Link budget for OQPSK...................................2-5
2-4 Link budget for UQPSK...................................2-6
2-5 Bandwidth comparisons...................................2-7
3-1 Comparison of computed and permissible C/I levels for HRPT reception..............3-2
3-2 Comparison of computed and permissible C/I levels for CDA reception..............3-2
3-3 Discrimination required for co-channel operation........3-3
3-4 Composite transmitter power density limits..............3-5
3-5 FDR between current and post-M transmissions............3-6
4-1 Baseline CDA link power budget..........................4-2

1. INTRODUCTION

1.1 Background

The Post NOAA-M Polar Orbiting Meteorological Satellites (POMS) will have instrument payloads that generate greater amounts of data than their predecessors. It will be necessary to broadcast data from certain instruments in real time as in present High Resolution Picture Transmission (HRPT) downlinks, but the composite rate will be about 3.5 Mbps or about five times that of the present HRPT broadcasts. It will also be necessary to continue transmission of recorded data such as Local Area Coverage (LAC) and Global Area Coverage (GAC) data on command to Command Data Acquisition (CDA) stations, but the data rate will be increased to as high as 50 Mbps from the present 2.667 Mbps rate. Because of the unavoidable increase in CDA downlink bandwidth, it has been decided to move CDA downlinks from the confined 1700 MHz region to the 7450-7550 MHz band and retain HRPT downlink operations near 1700 MHz. This document is intended to provide guidance for the design and implementation of post-NOAA-M HRPT and CDA downlinks with the objectives of: (1) minimizing the modifications needed to current HRPT receiving systems and (2) achieving electromagnetic compatibility among post-NOAA-M systems and other systems operating in the same frequency ranges.

1.2 Document Contents

This document recommends a modulation technique for post-NOAA-M HRPT downlinks and defines the conditions under which Electromagnetic Compatibility (EMC) is achieved for both the HRPT and CDA downlinks.

Section 2 assesses the post-NOAA-M HRPT transmission requirements, evaluates the impact of HRPT alterations on existing users, recommends that UQPSK modulation be selected to minimize impact on current users, and outlines the modifications needed to HRPT receivers for upwards compatibility with the new HRPT.

Section 3 examines the RF interference ramifications of the post-NOAA-M HRPT transmissions to determine an appropriate frequency plan.

Section 4 examines the RF interference ramifications of the post-NOAA-M CDA transmissions and indicates the available design variations within which electromagnetic compatibility is achieved.

1.3 Document Use

This document is for use by NOAA in considering the design and implementation of post-NOAA-M satellites. Others may also find this document useful, but should be aware that the design and implementation considerations and recommendations presented herein are subject to change.

2.0 HRPT USER-BASED LINK DESIGN CONSIDERATIONS

2.1. Introduction

The data transmission rate of the HRPT broadcast service from Post-NOAA-M POMS is expected to increase from the current rate of 0.665 Mbps to approximately 3.5 Mbps. This will have an impact on the present HRPT users since the current receivers are designed to handle only the lower data rate. Accommodating the new data rate while minimizing the impact on current users can be accomplished by carefully selecting the data encoding and modulation technique.

This section reviews NOAA and user requirements for post-NOAA-M HRPT, describes two candidate HRPT modulation techniques: 1) OQPSK (offset quadrature phase shift keying), and 2) UQPSK (unbalanced QPSK), and examines the modifications needed to existing HRPT receivers for operation with each modulation candidate in arriving at a recommended modulation (UQPSK).

2.2 Fundamental Requirements

Currently, the NOAA satellite instrument complement includes an Advanced Very High Resolution Radiometer (AVHRR) that provides information for global and local weather forecasting, global sea ice monitoring, and atmospheric studies. This AVHRR data constitutes most of the HRPT data, which is Manchester encoded at 0.665 Mbps and transmitted as a bi-phase modulated signal. The new HRPT downlink requires a data rate on the order of 3.5 Mbps and is again predominantly composed of data from the Advanced Medium Resolution Imaging Radiometer (AMRIR), which is replacing the present AVHRR instrument. The AMRIR is an eleven channel instrument which includes the six channels from AVHRR plus four sounding channels and one additional channel for sea surface temperature. The resolution of the AMRIR is 800 meters versus 1.1 km for the AVHRR.

Post-NOAA-M HRPT data must be received at a rate of 3.5 Mbps by earth stations equipped with a 2.4 meter diameter parabolic reflector antenna (or equivalent) exhibiting a nominal antenna gain of 30 dBic (relative to a circularly polarized isotropic antenna) and with a low-noise receiver system exhibiting a nominal noise figure of 2.3 dB (approximately 200 K noise temperature). Satellite power should be sufficient to permit the bit error ratio (BER) for the HRPT link to be less than 10^{-6} when operating at an elevation angle of 0° or more [3].

To accommodate the higher data rate, it is desirable to use a data encoding and modulation technique that is spectrally efficient. This goal is important for two reasons: (1) the bandwidth available in the 1700 MHz region is insufficient to accommodate significantly wider HRPT signal bandwidths, and (2) minimizing the increase in signal bandwidth over that of the present HRPT signals improves the upward compatibility of existing receivers. Power efficiency is also of concern.

2.2.1 Bandwidth Available for HRPT

The interference which could occur between HRPT transmissions from two POMS (Appendix A) indicates that their carrier frequencies should be offset in order to prevent mutual interference at earth stations at high latitudes. Two well-separated carrier frequencies (i.e., 1698 MHz and 1707 MHz) have been established for current HRPT transmissions which confine the main emission lobes to within the 1696.67-1708.33 MHz band. In addition to protecting HRPT, this enables two NOAA POMS to operate without risk of mutual interference with respect to CDA downlinks centered at 1702.5 MHz. The more detailed considerations of EMC for post-NOAA-M HRPT (Section 3), indicate that the post-NOAA-M HRPT modulation technique should be selected to allow: (1) continued operation on either of two frequencies; (2) occupied bandwidths on the two frequencies being confined to the 1695.6-1710 MHz band; and (3) the minimum practical occupied bandwidths.

2.2.2 Bandwidth Considerations for Receivers

A preliminary report [1] presented factors to be considered in the development of a new HRPT data format to accommodate a data rate of up to 8 Mbps. (A data rate of 8 Mbps was being considered at the time of the referenced study.) The first part of that study established a reference HRPT receiving earth station. That model served as the basis from which to assess the impact of changes in the HRPT broadcast format on the current users. The reference earth station model consisted of a Datron 2.4 meter antenna system and a Microdyne 1100-AR telemetry receiver employing plug-in modules described in Table 2-1. The recommended bandwidths for current NOAA POMS downlinks are given in Table 2-2 [2].

2.2.3 Power Efficiency

The ORI report [1] also presented an evaluation of several modulation types in order to determine a preferred transmission method for data at an assumed 8 Mbps rate. Link budgets showed that for 8- and 16-PSK, or 8- and 16-QAM (quadrature amplitude modulation), the required satellite RF power exceeds 130 W, whereas 4-PSK (QPSK) required less than half that power for comparable performance. In addition, while the Spectral Power Flux Density (SPFD) required for reception of signals using modulation techniques with four or more signal states exceeded the international limits in all cases, the extent to which the limits are exceeded increases with the number of signal states. In consideration of these factors, and the fact that QPSK and BPSK have equivalent power efficiency, QPSK or its variants are greatly preferred.

Table 2-1 -- Reference earth station receiver modules

Module	Model No.	Bandwidth
RF Tuner	1116-VT	7.5 MHz
First IF Filter*	100-159	4.0 MHz
Second IF Filter	1130-1	3.3 MHz
Demodulator	1151 4.5 rads, p-p deviation	6.0 MHz
Video Filter	1100-AR (chassis)	2.0 MHz

* The first IF filter is optional (not needed for effective HRPT reception).

Table 2-2 -- Recommended receiver bandwidths

Link	Module Type	Bit Rate (Mbps)	Data Format	Mod BW (1)	Min Mod BW (2)	Min IF BW (3)	Min IF BW (4)	LPF Video BW (5)
Stored TIP	PSK	0.33	Sϕ	2.864	2.864	3.007	3	0.66
HRPT	PSK	0.66	Sϕ	5.729	4.8	4.943	5	1.33
LAC/GAC	PSK	1.33	Sϕ	11.544	5.32	5.463	5	2.66
LAC/GAC	PSK	2.66	NRZ	11.544	5.32	5.463	5	2.66

Notes:

1) Determined by 2BR(1+ m) for NRZ and 4BR(1+ m) for split-phase (Sϕ) where BR is the bit rate and m is the phase deviation in radians).
2) Bandwidth after transmitter filtering.
3) Bandwidth including stability and doppler effects.
4) Standardized bandwidth.
5) Twice the bit rate for Sϕ and the bit rate for NRZ.
6) Standard filter bandwidth.

2.3 Candidate Modulations Methods

In consideration of post-NOAA-M HRPT requirements, OQPSK is evaluated as a bandwidth efficient modulation technique that could operate within the confines of the present HRPT emission. At the expense of greater occupied bandwidth, UQPSK is evaluated as a candidate modulation technique because it can maintain backward compatibility with the existing HRPT transmission format with minimal changes to HRPT receivers and signal processing equipment. Other QPSK variants have no special advantages.

2.3.1 OQPSK

OQPSK is a variation of QPSK in which the symbol transitions of the I- and Q-channels (in-phase and quadrature) are offset by one-half of a symbol period. This eliminates the 180° phase changes possible with QPSK by limiting the phase changes to 0° or 90°. Since the phase changes are in smaller steps, OQPSK, when compared to QPSK, will tend to suffer less degradation due to bandpass filtering and amplification in a nonlinear amplifier (e.g., spacecraft transmitter power amplifier). The power and bandwidth efficiency of OQPSK is identical to that of QPSK [5].

Table 2-3 presents a link budget for OQPSK operating at a 3.5 Mbps data rate (a symbol rate of 1.75 Msps). A 40 W spacecraft transmitter is required in order to achieve the BER requirement with an operating margin of 2.0 dB to allow for interference and other degradations not shown in the link budget. At a 5° earth station antenna elevation angle, the margin increases to 3.4 dB; however, the SPFD is -150.4 dB(W/m·4 kHz), which exceeds the limit specified in the Radio Regulations by about 4 dB. This can be mitigated as described in Section 3.

2.3.2 UQPSK

Unbalanced QPSK (UQPSK) is a form of QPSK for which the I- and Q-channels of the signal are modulated by independent binary data streams. Each channel may have a different data rate and a different power level. Several programs either use or plan to use UQPSK, including the Tracking and Data Relay Satellite System (TDRSS), NAVSTAR GPS, the Venus Orbiting Imaging Radar (VOIR), and other deep space probes [5]. With UQPSK it is possible to use the present HRPT data format and modulation technique on the I-channel and a new data format with a higher data rate on the Q-channel. The data on the I channel is assumed to be at a data rate of 0.665 Mbps, Manchester encoded and bi-phase modulated with a peak deviation of 90°. The Q channel would be bi-phase modulated at a rate approaching 2.9 Mbps (the difference between the overall data rate of 3.5 Mbps and the 0.665 Mbps HRPT data rate) and NRZ encoded.

The UQPSK link budget given in Table 2-4 shows that a spacecraft transmitter with 35 W power provides adequate power to achieve a reliable link to HRPT Earth stations operating at an elevation angle of 5°. The power in the I-channel would be set to

Table 2-3 -- Link budget for OQPSK

Frequency	(MHz)	1700	
Satellite altitude	(km)	850	
Data rate	(Mbps)	3.5	
Earth station antenna elevation angle	(deg)	0.0	5.0
Transmitter Power	(Watts)	40.0	40.0
	(dBW)	16.0	16.0
Filter, cable loss	(dB)	-1.7	-1.7
VSWR loss	(dB)	-0.2	-0.2
Transmitting antenna gain	(dBic)	2.1	2.1
E.i.r.p.	(dBW)	16.2	16.2
Path loss	(dB)	-167.7	-166.2
SPFD	(dBW/m^2 4kHz)	-151.8	-150.4
Fading and rain loss	(dB)	-0.4	-0.4
Polarization loss	(dB)	-0.5	-0.5
Pointing loss	(dB)	-0.5	-0.5
Receiving antenna diameter	(m)	2.4	2.4
Receiving antenna gain	(dBic)	30.0	30.0
Receiver noise temperature	(K)	200.0	200.0
Antenna noise temperature	(K)	150.0	150.0
Receiving system temperature	(K)	350.0	350.0
Modulation filter loss	(dB)	-0.4	-0.4
Adjacent channel interference	(dB)	-0.5	-0.5
Demodulator loss	(dB)	-1.5	-1.5
Received E_b/N_o	(dB)	14.9	16.3
Theoretical E_b/N_o (BER = 10^{-6})	(dB)	10.5	10.5
Required E_b/N_o (BER = 10^{-6})	(dB)	12.9	12.9
Margin	(dB)	2.0	3.4

Table 2-4 -- Link budget for UQPSK

Frequency	(MHz)	1700	
Satellite altitude	(km)	850	
Earth station antenna elevation angle	(deg)	5.0	
Channel		I	Q
Data format		Manchester	NRZ
Data rate	(Mbps)	.665	2.84
Transmitter Power	(Watts)	7.0	28.0
	(dBW)	8.5	14.5
Filter, cable loss	(dB)	-1.7	-1.7
VSWR loss	(dB)	-0.2	-0.2
Transmitting antenna gain	(dBic)	2.1	2.1
E.i.r.p.	(dBW)	8.7	14.7
Path loss	(dB)	-166.2	-166.2
SPFD	(dBW/m -4 kHz)	-156.5	-154.0
Fading and rain loss	(dB)	-0.4	-0.4
Polarization loss	(dB)	-0.5	-0.5
Pointing loss	(dB)	-0.5	-0.5
Receiving antenna diameter	(m)	2.4	2.4
Receiving antenna gain	(dBic)	30.0	30.0
Receiver noise temperature	(K)	200.0	200.0
Elevation angle	(deg)	5.0	5.0
Antenna noise temperature	(K)	150.0	150.0
Receiving system temperature	(K)	350.0	350.0
Modulation filter loss	(dB)	-0.4	-0.4
Adjacent channel interference	(dB)	-0.5	-0.5
Demodulator loss	(dB)	-1.5	-1.5
Received E_b/N_o	(dB)	16.0	15.7
Theoretical E_b/N_o (BER = 10^{-6})	(dB)	10.5	10.5
Required E_b/N_o (BER = 10^{-6})	(dB)	12.9	12.9
Margin	(dB)	3.1	2.8

7 Watts, leaving 28 Watts for the Q-channel. For these settings, the performance margin in both channels will be in excess of 1.7 dB and 1.3 dB, respectively, at a 0° earth station antenna elevation angle to allow for interference and other degradations. It is noted that the SPFD of the composite emission at the surface of the Earth exceeds the international limit by about 3 dB for an elevation angle of 5°.

2.4 User-Equipment Tradeoffs Between OQPSK and UQPSK

The choice between the OQPSK and UQPSK candidates can be made on the basis of minimum impact on HRPT users, other factors being essentially equal. The link power budgets for both modulations have been selected to allow continued use of existing receiver antenna subsystems. However, the impact on receiver and data processing subsystems differs for these modulations as described below, such that UQPSK is the favored modulation.

2.4.1 Impact on Receiver System

Table 2-5 summarizes bandwidths for the candidate modulations, which can be compared with those of the reference receiver (Table 2-1). Both modulations have RF bandwidths smaller than the bandwidth of the reference receiver's RF tuner and both require IF bandwidths in excess of the reference receiver's first and second IF. However, the required video bandwidth for OQPSK exceeds that available in the reference receiver, whereas an I channel demodulator output of the UQPSK signal has the same bandwidth as the present HRPT signal and can utilize existing video filter/amplifier subsystems in current HRPT receivers. Thus, the segment of the HRPT user community wishing to receive only HRPT data of the current type would benefit from the choice of UQPSK (a savings of approximately $200 by retention of the video filter).

Table 2-5 -- Bandwidth comparisons

Modulation & Channel	Channel Bit Rate	Bandwidths RF (1)	Bandwidths IF (2)	Bandwidths Video (3)
OQPSK-I	1.75 Mbps	4.15 MHz	4.30 MHz	3.5 MHz
OQPSK-Q	1.75 Mbps			
UQPSK-I	0.665 Mbps	6.88 MHz	7.03 MHz	1.33 MHz
UQPSK-Q	2.835 Mbps			2.835 MHz

Notes:

1) Bandwidth of emission after transmitter filtering.
2) Bandwidth including transmitter stability (34.14 kHz) and Doppler (37.5 kHz) effects, as for current HRPT system [2].
3) Twice the bit rate for Sϕ and the bit rate for NRZ.

2.4.2 Impact on Data Processing System

The data processing subsystem consists of the bit synchronizer, frame synchronizer, computer processing (with data storage) and display elements. Simply stated, UQPSK affords the opportunity to retain all of this receiver equipment with operation on only the I-channel (software/ROM changes may be needed), whereas OQPSK requires new synchronizers as a minimum. Thus, many users would benefit from the selection of UQPSK.

2.5 Required Receiver Modifications

The data format on the I-channel could be made to conform with the format currently used for HRPT transmissions (described in [6]), through satellite on-board signal processing, so as to preclude the need for any modifications to the data processing subsystem and resident software. However, depending on the final design of the instruments, data averaging (for resolution conversion) and multi-channel parameter inference algorithms (for creating virtual sensor channels matching prior channel types) could be needed in the spacecraft or earth station to obtain a replica of current HRPT data stream. Regardless, the I channel would contain the frame synchronization words and any other data necessary for autonomous receiver operation.

Use of the Q-channel which would contain data not previously available to HRPT users requires additional receiver and data processor modifications. Accordingly, two user cases are addressed below: (1) users wishing to receive only the present type of HRPT (I-channel reception), and (2) users wishing to receive the full, enhanced data from post-NOAA-M satellites (I- and Q-channel reception).

2.5.1 I-Channel Reception

Reception of only the I-channel in the UQPSK signal precludes the necessity to replace the bit synchronizer, frame synchronizer, and data manipulation and display equipment used in the present HRPT Earth stations. However, in order to receive the new downlink modulation, the receiver must pass both the I- and Q-channels to the demodulator without significant distortion. Specifically, the rated bandwidths of the RF and IF subsystems must exceed the UQPSK signal bandwidth (nominally 7.03 MHz) and the transient response must be sufficient to preclude significant inter-symbol interference (e.g., phase linearity to within less than 10° and, generally, a slow initial amplitude roll-off beyond the passband).
Note that for the reference receiver described in Table 2-1, the RF section meets the bandwidth requirement, but the IF filter(s) would have to be replaced.

Most of the demodulators in current HRPT receivers are unlikely to handle the proposed UQPSK (or any QPSK) signal, primarily because of inappropriate carrier recovery circuitry (e.g., relying on absence of a Q channel) or bandwidth limitations (e.g., the 6 MHz bandwidth of the reference receiver demodulator is marginal). It may be possible to adapt certain types of existing BPSK demodulators, but this is unlikely to be practical in many cases (e.g., the reference receiver demodulator module listed in Table 2-1 would likely require a new circuit board). Generally, a Costas loop is used the coherently demodulate an UQPSK carrier [7], [8], and [9]. In any case, the demodulator I-channel output signal (properly conditioned) would be compatible with all successive HRPT receiver system circuitry (video, and signal/data processing).

2.5.2 Q-Channel Reception

In the process of assuring proper reception of the I-channel as described above, the Q-channel also becomes available as a demodulator output. However, a video filter for the demodulator Q-channel output must be added to the basic I-channel HRPT receiving system. Beyond the baseband video, a number of Q-channel bit synchronizer and composite or segregated I/Q data processing options can be considered. In many cases, the relatively high data rate of the Q-channel (2.9 Mbps) will necessitate additional, new or greatly modified data processing and display elements.

3. ELECTROMAGNETIC COMPATIBILITY OF HRPT DOWNLINKS

3.1 Introduction

This Section provides guidelines for the HRPT frequency plans and transmitter filters for post-NOAA-M satellites based on interference considerations. Section 3.2 addresses constraints needed to prevent unacceptable interference among 1700 MHz downlinks from POMS operated by NOAA and by other administrations, and from HRPT downlinks to other systems. These constraints are compiled and summarized in Section 3.3 in the form of frequency plans and in Section 3.4 in the form of general transmitter filter specifications.

3.2 Interference Considerations

In the current NOAA HRPT downlink frequency plan, most of the emission power is confined to the overall band 1695.6 MHz to 1709.4 MHz (not including emission sidebands, transmitter frequency tolerances, and Doppler effects). Services other than the meteorological-satellite service are permitted to use this band and the ajacent bands under the international Radio Regulations; however, within the meteorology community, this band (extending up to 1710 MHz) is tacitly reserved for POMS as opposed to geostationary meteorological satellites or radiosondes. Two categories of potential interference interactions are examined below: (1) interference among POMS operating in the 1695.6-1710.000 MHz range, and (2) interference between POMS and other systems. NOAA has taken initiatives in the International Radio Consultative Committee (CCIR) to establish interference and frequency sharing criteria for 1700 MHz POMS downlinks, and criteria exist, for other potentially affected services, which can be applied to determine constraints on post-NOAA-M HRPT transmissions that will assure their electromagnetic compatibility.

3.2.1 Interference Among POMS

An HRPT downlink from a post-NOAA-M satellite must operate compatibly with downlinks from other POMS, including those of other post-NOAA-M POMS, NOAA predecessors to post-NOAA-M (i.e., during the transition to a post-NOAA-M constellation), and POMS operated by other countries (e.g., China [10]). The permissible levels of interference applicable in this analysis real-time data (e.g., HRPT) and stored-data (e.g., CDA) downlinks from POMS satellites are given in a CCIR Report [11].

Appendix A shows the statistics of interference computed for normalized cases of interference between downlinks from identical POMS in AM and PM orbits (e.g., two post-NOAA-M POMS). These C/I levels are compared in Tables 3-1 and 3-2 with the CCIR interference criteria for HRPT and CDA transmissions, respectively. The margins in the tables indicate the amounts by which the permissible interfering signal power levels exceed the levels computed for the normalized cases. The smaller of the two margins (i.e., short-term and long-term) for the same earth station latitude, if negative, is the amount of extra discrimination against interference that might be needed in order to meet the CCIR frequency sharing criteria. Conversely, if the smaller of the two margins is positive, the smaller margin indicates the amount by which deviations can occur from the normalized case without risking unaccepatble interference (e.g., interfering POMS could use the same carrier frequency as the victim downlink, but have antenna input power that is higher than that for the victim POMS by the amount of the margin).

Table 3-1 -- Comparison of computed and permissible C/I levels for HRPT reception

Earth Station Latitude	Percentage of Time Threshold C/I is Not Exceeded		Margin (dB) for p% of the Time	
	C/I = 29.3 dB	C/I = 17.0 dB	p = 20%	p = 0.006%
30°	0.0882	0.0	+ ∞	+ 11.0
65°	5.63	0.989	+ 18.7	- 17.0

Table 3-2 -- Comparison of computed and permissible C/I levels for CDA reception

Earth Station Latitude	Percentage of Time Threshold C/I is Not Exceeded		Margin (dB) for p% of the Time	
	C/I = 30.1 dB	C/I = 12.5 dB	p = 20%	p = 0.006%
65°59'	0.076	0.0	+ ∞	+ 15.8

For a mid-latitude (30°) HRPT earth station, interference occurs in the normalized case from a POMS for less than 0.03% of the reception time (i.e, long-term interference is of no concern), and short term (0.006% of time) interference is safely below permissible levels by an 11 dB margin. However, for HRPT reception at high latitudes (65°), interpolation (log-log) between permissible levels of interference for 20% and 0.006% of the time indicates that the permissible levels of interference are exceeded for about 0.3% of the reception time. The margins given in Table 3-1 indicate that an additional 17 dB of discrimination is needed in the normalized case in order to meet the short term criteria at high latitudes with the reference earth station (8 foot antenna).

For an earth station receiving stored-data at high latitudes (e.g., CDA), the interference computed for the normalized case (Table 3-2) is safely below the permissible levels by a margin of 15.8 dB.

In order to transform the results for the above normalized cases to apply to actual interactions among the affected POMS downlinks, actual carrier power levels, modulations, frequency plans and transmitter (modulation) filter characteristics must be considered. Table 3-3 presents the results of adjusting only for NOAA POMS carrier power levels, which relate, therefore, to co-channel operation. The indicated discrimination requirements can be readily met with the post-NOAA-M frequency plan delineated in Section 4.3. The following nominal satellite transmitter output spectral power densities are assumed in Table 3-3:

- NOAA-M/predecessor HRPT:
  - as an interferer, -55.3 dBW/Hz (average over 1 MHz)
  - as a victim, -56.0 dBW/Hz (outside residual carrier spike)

- NOAA-M/predecessor CDA: -59.1 dBW/Hz

- Post-NOAA-M HRPT (UQPSK):
  - victim I channel, -55.5 dBW/Hz
  - victim Q channel, -52.8 dBW/Hz
  - total as interferer, -50.8 dBW/Hz (in current HRPT channel)
  - total as interferer, -51.8 dBW/Hz (in current CDA channel)

Table 3-3 -- Discrimination required for co-channel operation*

Victim Downlink System	Interfering Downlink System: Real-Time Transmissions, NOAA-M or Predecessor	Real-Time Transmissions, Post-NOAA-M	Stored-Data Transmissions NOAA-M/predecessor
NOAA-M or Predecessor HRPT	Not Applicable	22.2 dB	Not Applicable
NOAA-M or Predecessor CDA	Not Applicable	0.0 dB	Not Applicable
Post-NOAA-M I Channel	17.2 dB	21.7 dB	13.4 dB
Post-NOAA-M Q Channel	14.5 dB	19.0 dB	10.7 dB

* Assumes that HRPT downlinks to small earth stations (8 foot antenna) operating at high latitudes are protected in accordance with CCIR frequency sharing criteria [11]; those criteria are met at mid-latitudes in the absence of additional discrimination.

3.2.2 Interference From Post-NOAA-M HRPT to Other Services

Limits on the power density of satellite emissions have been established for the protection of systems that may be affected by post-NOAA-M transmissions. These are compiled below and summarized in the form of an emission mask.

Radiosondes in the meteorological aids service may operate in the 1668.4-1700 MHz band [12] and are protected from satellite emissions with a Spectral Power Flux Density (SPFD) limit. However, insofar as the occupied bandwidth of current POMS HRPT downlinks extends to as low as 1695.6 MHz, and the bandwidth above that frequency is understood within the meteorological community to be primarily for POMS, the SPFD limit should have to be met only below the 1695.6 MHz frequency. The SPFD limit is as follows [4]:

-133 dBW/m$^2\cdot$1.5 MHz (any angle of arrival on Earth)

The fixed and mobile (radio-relay) services may operate in the bands 1668.4-1690 MHz and 1700-2290 MHz and are protected by the following SPFD limit [4]:

-154 dBW/m$^2\cdot$4kHz, $\qquad 0° \leq \theta \leq 5°$

-154 dBW/m$^2\cdot$4kHz $+ 0.5(\theta - 5)$, $\qquad 5° < \theta < 25°$

-144 dBW/m$^2\cdot$4kHz, $\qquad 25° \leq \theta \leq 90°$

where θ = angle of arrival on Earth (elevation angle)

Geostationary meteorological satellites operating in the 1694.3-1694.7 MHz band are protected by the following limit on spacecraft antenna power density, based on protection of NOAA GOES Data Collection Platform (DCP) operations [13]; this limit is extended to 1695 MHz to protect a 1694.8 MHz DCP carrier:

$-$ 32 dBW/3 kHz (antenna input power density)

Finally, the radio astronomy service may operate in the band 1660-1670 MHz and is protected by the following SPFD limit [14]:

$-$ 237 dBW/m$^2\cdot$Hz, for all angles of arrival

The above limits are summarized in Table 3-4 in the form of limits on post-NOAA-M transmitter output power density limits as a function of frequency. For the purposes of converting SPFD limits to transmitter output power density limits, it is assumed that a current NOAA POMS S-band antenna or a comparable shaped-beam spacecraft antenna is used and spacecraft transmitter line losses total 2 dB. It should be noted that additional supression requirements may be specified for post-NOAA-M transmitter spectra. This is subject to further study.

Table 3-4 -- Composite transmitter power density limits

Frequency Range (MHz)	Specified SPFD or Power Density Limit (1)	Equivalent Transmitter Power Density Limit (2)
1660.0- 1670.0	SPFD $-237\ dBW/m^2 \cdot Hz$	-68.0 dBW/3 kHz (4)
1670.0 1694.3	SPFD $-133\ dBW/m^2 \cdot 1.5\ MHz$	-25.8 dBW/3 kHz (4)
1694.3- 1695.0	Power Density -32 dBW/3 kHz	-32 dBW/3 kHz
1695.0- 1695.6	SPFD $-133\ dBW/m^2 \cdot 1.5\ MHz$	-25.8 dBW/3 kHz (4)
1700.0- 2290.0	SPFD (3) $-154\ dBW/m^2 \cdot 4\ kHz$	-15.1 dBW/3 kHz

Notes:

(1) Bandwidth units are as specified for the limit.

(2) Where the bandwidth specified with the limit exceeds 3 kHz, the power per 3 kHz is averaged over specified BW with a 2 dB allowance for peak-to-average signal densities.

(3) For the assumed spacecraft antenna and orbit altitudes on the order of 850 km, the elevation angle dependency of SPFD limits to protect the fixed and mobile services are most constraining at 5° elevation. (5° SPFD limit is shown).

(4) The highest SPFD occurs on Earth at 50° of nadir, and is used in determining the power density limit where SPFD limits are not dependent on elevation angle.

Note that in the last row of Table 3-4, there is a power density limit of -15.1 dBW/3 kHz imposed on the HRPT transmitter in-band (carrier) emission output. With the proposed UPSK emission, the composite transmitter power density (power addition of I- and Q-channels) is its highest about 665 kHz away from the carrier (-13.2 dBW/3 kHz), and exceeds the limit over a bandwidth of about 2 MHz. While the link budet (Table 2-4) leading to this situation includes an excess-power margin on the order of 3 dB, that nominal margin is needed for degradations not included in the budget (e.g., interference-noise and reduction in power at end-of-life. This violated in-band limit is based on the SPFD specified for the protection of fixed and mobile services; however, analyses have shown that the specified SPFD limit may be overly conservative (by up to 17 dB) with respect to interference from satellites in low-Earth-orbit [15]. Consequently, a waiver of the SPFD limit should be sought in conjunction with the NOAA submissions to the Spectrum Planning Subcommittee (the federal government spectrum management committee, charged with review of planned systems for verifying EMC and conformance with applicable radiocommunications regulations).

3.3 Frequency Plans

The discrimination requirements indicated in Table 3-3 can be pursued by arranging frequency plans for post-NOAA-M satellites to take advantage of receiver Frequency Dependent Rejection (FDR) resulting from filtering. If the achieved FDR is less than the "required" discrimination, the CCIR interference criteria will not be met. However, performance may nevertheless be at acceptable levels, depending on receiver location, the presence of other interfering systems, and the statistics of the interference.

Figure 3-1a illustrates the current NOAA frequency plan for HRPT and CDA transmissions during normal operating modes. (In the event of failure of the 1702.5 MHz transmitter normally used for CDA, the 1698 MHz or 1707 MHz transmitter can be used for CDA). Considering the discrimination requirements of Table 3-3 for interactions between post-NOAA-M and the current operations depicted in Figure 3-1a, and the desire to confine post-NOAA-M HRPT emissions to the tacit POMS band 1695.6-1710 MHz, the frequency plan shown in Figure 3-1b would afford the greatest possible frequency separations to provide FDR where needed. This proposed frequency plan provides greater than 60 dB of FDR between two post-NOAA-M HRPT transmissions.

The worst case frequency plan interactions with respect to current NOAA satellites are depicted in Figure 3-1c, assuming that HRPT from a current satellite occurs at the opposite end of the frequency band from the post-NOAA-M HRPT. The nominal interactions with current CDA and HRPT transmissions are listed in Table 3-5.

Table 3-5 -- FDR between current and post-M transmissions

Victim Transmission	Interfering Transmission: Current CDA	Current HRPT	Post-M HRPT
Current CDA	Not Applicable	Not Applicable	None Needed
Current HRPT	Not Applicable	Not Applicable	60 dB
Post-M I-Channel	17 dB	60 dB	60 dB
Post-M Q-Channel	15 dB	60 dB	60 dB

Table 3-5 indicates that for the recommended post-NOAA-M frequency plan (Figure 3-1b), the required discriminations (Table 3-3) are met in all cases. The case of current CDA transmissions interfering with post-NOAA-M downlinks is met with the smallest margin, nominally 4 dB.

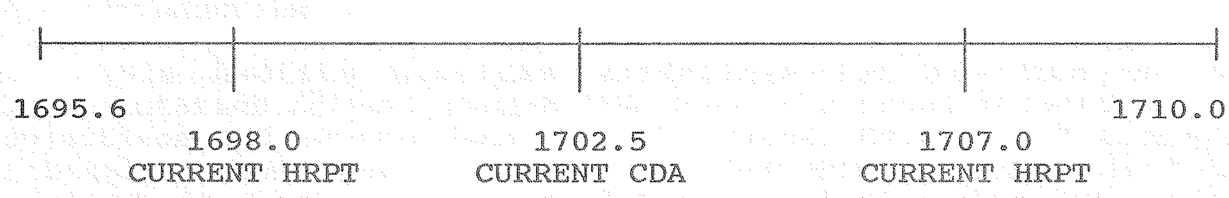


Figure 3-1a -- NOAA-M/predecessor frequency plan

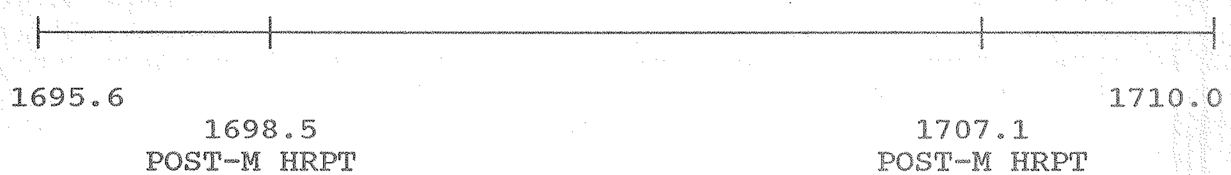


Figure 3-1b -- Proposed post-NOAA-M frequency plan

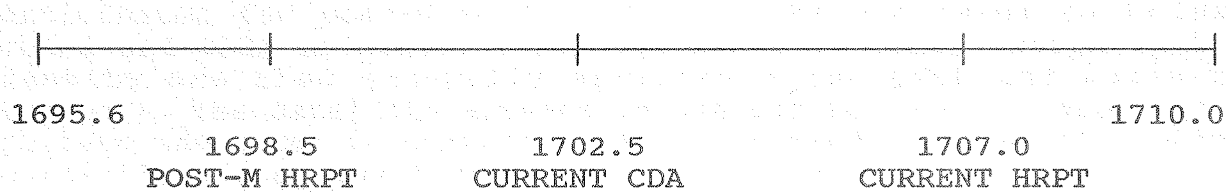


Figure 3-1c -- Worst case frequency use during transition

3.4 Transmitter Filters

The spectral power distribution with frequency should fall below the envelope defined in Table 3-4. This will occur with modulation filters for the I- and Q-channels similar to those now used (5th order, 0.05° equiripple phase, with half-power bandwidths set at 90-95% of the first null in the spectral power distribution of the baseband data stream [13]). It should be noted that in the general link budget in Section 2 (Table 2-4), a nominal degradation allowance of 1.7 dB has been made for transmitter output filters and RF cables.

4. ELECTROMAGNETIC COMPATIBILITY OF CDA DOWNLINKS

4.1 Introduction

This Section provides guidelines for the design and implementation of post-NOAA-M CDA downlinks based on performance objectives and interference considerations. Section 4.2 presents a baseline link power budget for a 7500 MHz CDA link, which is applied in Section 4.3 to determine design and operating constraints needed to prevent unacceptable interference between CDA downlinks and other systems.

4.2 Baseline CDA Link Power Budget

Table 4-1 presents a baseline noise power budget for a CDA link operating at 7500 MHz. The column labelled "short term performance analysis" lists parameter values assumed to correspond with BERs which are exceeded for no more than 0.1% of the reception time. The column labelled "long term performance analysis" lists parameter values assumed to correspond with BERs which are exceeded for no more than 20% of the reception time.

The satellite characterized in Table 4-1 is assumed to be designed with sufficient end-of-life power and e.i.r.p. to just meet a 10^{-6} Bit-Error-Ratio (BER) performance objective during relatively degraded operating conditions that occur for only 0.1% percent of time. The assumed data rate is 50 Mbps (maximum anticipated for post-NOAA-M) and the data are taken to be NRZ coded and BPSK modulated (although all parameters except power density are also generally applicable for QPSK and variants thereof). The satellite antenna is assumed to have a shaped -gain pattern identical to current NOAA POMS S-band antennas [2], which partially offset the increase in free space loss on signal paths from the satellite at increasing off-nadir angles.

The short-term path loss in excess of free space is the rain fade depth predicted for rain zone K (CCIR Report 763/1986). The rain fade model of CCIR Report 564/1986 was used. Rain zone K has rain rate statistics applicable to Wallops Island, which produce far deeper signal fades with a given probability than do the rain climates for Gilmore Creek and Tromso. The long term value for path loss in excess of the free space level is based on expected gaseous attenuation.

The earth station has a 40 foot diameter antenna (nominally 54 dBi gain), which represents a candidate CDA station at Tromso, Norway. The Tromso station may supplement the Wallops Island, VA, and Gilmore Creek, AL, CDA earth stations, which have 85 foot antennas (nominally 64.8 dBi gain) and would far exceed the performance objectives under the above assumptions (i.e., a 10.8 dB operating margin). The minimum operational elevation angle for the earth station antenna (Item 4b) is taken to be five degrees and is assumed to be the elevation angle occurring for 0.1% of the time. An 8° elevation angle would be exceeded for all but about 20% of the time. These assumed elevation angles are conservatively low, insofar as current operational needs and physical constraints are concerned. The noise bandwidth for the assumed receiver is nominally 100 MHz. Estimated intra-system noise power density allowances (Item 19a) include Earth and precipitation contributions. The inter-system interference allowance is that specified by the CCIR [16].

TABLE 4-1 -- Baseline CDA link power budget

Performance Factor	Short Term Analysis	Long Term Analysis
1. Satellite transmitter output power (dBW)	16.0	16.0
2. Filter/cable losses (dB)	1.7	1.7
3. Impedance mismatch losses (dB)	0.2	0.2
4. Satellite antenna gain (dBi)		
a. 61° off-nadir (8° elevation)	-	2.0
b. 62° off-nadir (0° elevation)	2.1	-
5. Satellite e.i.r.p. (dBW)	16.2	16.1
6. Free space loss (dB)		
a. 8° elevation	-	176.9
b. 0° elevation	179.1	-
7. Excess path loss (dB)	3.7	0.5
8. Earth station antenna gain (dBi)	54.0	54.0
9. Antenna pointing error (dB)	0.5	0.5
10. Polarization mismatch loss (dB)	0.2	0.2
11. Residual carrier loss (dB)	-	-
12. Demodulator implementation loss (dB)	2.0	2.0
13. Received signal power (dB)	-115.3	-110.0
14. Data rate, 50 Mbps (dB bits/second)	77.0	77.0
15. Received energy-per-bit, E_b (dBW/Hz)	-192.3	-187.0
16. Receiver system noise temperature (K)	320.0	210.0
17. Receiver noise power density (dBW/Hz)	-203.5	-205.4
18. Adjacent channel interference (dBW/Hz)	-	-
19. Intra-system noise power density, E_b (dBW/Hz)	-203.5	-205.4
20. E_b/N_o (dB)	11.2	18.4
21. Link BER, coherent BPSK	5×10^{-7}	$<10^{-12}$
22. Satellite data storage/handling error ratio	5×10^{-7}	5×10^{-7}
23. Total link bit error ratio	1×10^{-6}	5×10^{-7}

4.3 Design and Implementation Constraints Due To Interference

The 7450-7550 MHz band is intensively used by systems in the fixed-satellite service (space-to-Earth), and fixed and mobile (radio-relay) services. Numerous satellites that can interfere with CDA reception are currently deployed throughout the geostationary orbit, and the deployment rate indicates that the long term scenario could reach a one-satellite per 3° density. Likewise, the deployment of terrestrial fixed and mobile stations in this band is dense, with several transmitting stations being located in proximity to Wallops Island, Gilmore Creek and Tromso. In short, no special design constraints appear to accrue from interference problems; however, analyses are needed of the potential interference to CDA receivers from proximate terrestrial radio-relay transmitters.

4.3.1 Impact of Interference from Satellites

Appendix B presents an analysis of interference between satellites in the fixed-satellite service and CDA earth stations, considering interference to both the CDA and fixed-satellite service earth stations. This analysis shows that with the link budget of Table 4-1, unacceptable interference is not likely to occur. It is also shown that the interference criteria for CDA operations are met with a smaller margin than are the criteria for the fixed-satellite service, thus providing latitude to increase the CDA transmitter output power level (by up to perhaps 9 dB) or make other adjustments (e.g., to better serve an earth station having a 40 foot antenna).

It should be noted that the analysis assumes a post-NOAA-M spacecraft antenna having gain-shaping identical to that of current S-band antennas. This parameter has a strong influence on the statistics of interference. At the same time, achieving this shaping may be difficult. In the event that the increase in gain as off-nadir angle increases can not be at least as great for current S-band antennas, such that the Equivalent Isotropically Radiated Power (EIRP) towards nadir is much higher than assumed in this analysis, it may be necessary to consider transmitter power control or transmission scheduling constraints in order to protect operations in the fixed-satellite service.

4.3.2 Impact of Interference from Radio-Relay Stations

Prevention of interference to the fixed and mobile services is not a problem, insofar as the satellite EIRP assumed in Table 4-1 produces a SPFD that meets the international limit [4] with a margin of about 10 dB. This margin occurs at a 5° elevation angle and is the smallest margin over all elevation angles.

As for interference from fixed and mobile stations to the CDA receiver, regulatory procedures have been established for identifying all potential interferers, and for resolving the predicted problems on a case-by-case basis. Difficulties are not anticipated for Gilmore Creek because of the available terrain shielding; however, little shielding other than Earth curvature is available at the Wallops Island site and numerous potential interactions must be examined. Tromso, with its relatively small antenna, will be relatively sensitive to interference -- coordination of that prospective operation would occur under the auspices of the Norwegian authorities.

It should be noted that increasing the satellite power in order to minimize sensitivity of earth stations to interference is often more costly than other measures (e.g., scheduling transmissions to a problematic CDA station to avoid antenna pointing towards certain angular sectors where interference may occur).

4.3.3 Data Rate Impact

Insofar as CDA transmission schedules may have to be constrained to resolve interference problems that may evolve after post-NOAA-M implementation, the highest practical data transmission rate should be used. This will maximize the time margin available for scheduling transmissions to start before or after problematic angular regions are encountered.

APPENDIX A - INTERFERENCE AMONG DOWNLINKS FROM POMS AT 1700 MHz

A.1 Introduction

The purpose of this appendix is present statistics of RF interference among POMS, from continuous downlink transmissions to continuous and commanded downlink transmissions. The scenarios that were selected to produce "normalized" results are described, and the results of simulations of those scenarios are presented. The analysis results can be extrapolated to apply to all operating scenarios involving a post-NOAA-M satellite and another POMS.

A.2 Interference Scenarios

In order to determine "normalized" statistics of interference between transmissions from two POMS, identical POMS in circular AM and PM orbits have been assumed. In this case, the Carrier-to-Interference power ratio (C/I) would be 0 dB if the POMS were collocated in space. A reference HRPT earth station [c] is the receiver assumed for continous direct broadcasts and the Gilmore Creek CDA station (modified for 7500 MHz operation) is the receiver assumed for stored-data transmissions. Table A-1 summarizes the parameters assumed for the interference scenarios.

A.3 Simulation Results

Simulation were conducted to determine the RF C/I ratios occuring at the earth station receiver input, taking the AM satellite (9:30 AM descending node, 21:30 ascending node) to be the satellite that is tracked and received on all passes. The results of the simulations are listed in Tables A-2 and A-3 for the mid- and high-latitude HRPT cases, and Table A-4 for the CDA case, respectively.

Other simulations conducted with various ascending nodes and low-altitude orbits yield similar results for the same earth station. These simulations also indicate the following trends:

- As the latitude of the earth station is reduced (i.e., sites nearer the equator), a given level of interfering signal power is exceeded less frequently.
- As the gain (or diameter) of the earth station antenna is increased, a relatively high given level of interference (e.g., C/I < 20 dB) occurs less frequently.
- As the minimum earth station antenna elevation angle is increased or the minimum visibility time for reception is decreased (i.e., time above the minimum elevation angle), a given C/I level occurs less frequently.

Table A-1 -- Parameters assumed for analysis

Receiving Earth Stations

- locations: 30.00° & 65.00° latitudes for HRPT; Gilmore Creek for CDA (64°59'N, 147°30'W)
- minimum antenna elevation angle: 0° for HRPT and 5° for CDA
- minimum visibility time for attempted reception: 30 sec
- antenna gain: 29 dBic mainbeam (8 feet) for HRPT & 64.8 dBic (85 feet) for CDA; sidelobes as per CCIR Report 391-5

Satellites

Orbit Altitude (km)	Orbit Period (min)	Inclination (deg)	Solar Hour Angle Ascending Node (Hrs)
870	102.35	99.1	21.50
833	101.57	98.7	13.50

- Antenna input power: same for both satellites
- Antenna radiation pattern: both satellites use current NOAA antenna [a,b] and are co-polar

Table A-2 -- Results of HRPT simulation for mid-latitudes

Earth station latitude = 30°
Total elapsed time = 216,000 minutes
Total reception/tracking time = 5,098.5 minutes
Total time of POMS mutual visibility = 108.5 minutes

C/I Range (dB)	Duration (min.)	Fraction of Total Visibility	Cumulative Fraction of Visibility
C/I < 28.0	0.0	0.0	0.0
28.0 < C/I < 30.0	1.5	2.94E-04	2.94E-04
30.0 < C/I < 32.0	6.0	1.18E-03	1.47E-03
32.0 < C/I < 34.0	7.5	1.47E-03	2.94E-03
34.0 < C/I < 36.0	13.0	2.55E-03	5.49E-03
36.0 < C/I < 38.0	26.0	5.10E-03	1.06E-02
38.0 < C/I < 40.0	33.0	6.47E-03	1.71E-02
40.0 < C/I < 42.0	15.0	2.94E-03	2.00E-02
42.0 < C/I < 44.0	6.5	1.27E-03	2.13E-02
44.0 < C/I < 46.0	0.0	0.00E+00	2.13E-02
46.0 < C/I < ∞	0.0	0.00E+00	2.13E-02

Table A-3 -- Results of HRPT simulation for high latitudes

Earth station latitude = 65°
Total elapsed time = 216,000 minutes
Total reception/tracking time = 11,525.5 minutes
Total time of POMS mutual visibility = 1,955 minutes

C/I Range (dB)	Duration (min.)	Fraction of Total Visibility	Cumulative Fraction of Visibility
0.0 < C/I < 2.0	2.5	2.17E-04	2.17E-04
2.0 < C/I < 4.0	2.0	1.74E-04	3.90E-04
4.0 < C/I < 6.0	2.5	2.17E-04	6.07E-04
6.0 < C/I < 8.0	5.5	4.77E-04	1.08E-03
8.0 < C/I < 10.0	10.5	9.11E-04	2.00E-03
10.0 < C/I < 12.0	16.5	1.43E-03	3.43E-03
12.0 < C/I < 14.0	20.5	1.78E-03	5.21E-03
14.0 < C/I < 16.0	23.5	2.04E-03	7.24E-03
16.0 < C/I < 18.0	30.5	2.65E-03	9.89E-03
18.0 < C/I < 20.0	37.0	3.21E-03	1.31E-02
20.0 < C/I < 22.0	51.0	4.42E-03	1.75E-02
22.0 < C/I < 24.0	61.5	5.34E-03	2.29E-02
24.0 < C/I < 26.0	78.5	6.81E-03	2.97E-02
26.0 < C/I < 28.0	104.0	9.02E-03	3.87E-02
28.0 < C/I < 30.0	124.0	1.08E-02	4.95E-02
30.0 < C/I < 32.0	157.0	1.36E-02	6.31E-02
32.0 < C/I < 34.0	210.5	1.83E-02	8.13E-02
34.0 < C/I < 36.0	249.5	2.16E-02	1.03E-01
36.0 < C/I < 38.0	270.5	2.35E-02	1.26E-01
38.0 < C/I < 40.0	236.5	2.05E-02	1.47E-01
40.0 < C/I < 42.0	147.0	1.28E-02	1.60E-01
42.0 < C/I < 44.0	79.0	6.85E-03	1.67E-01
44.0 < C/I < 46.0	29.0	2.52E-03	1.69E-01
46.0 < C/I < 48.0	6.0	5.21E-04	1.70E-01
48.0 < C/I < 50.0	0.0	0.00E+00	1.70E-01
50.0 < C/I < ∞	0.0	0.00E+00	1.70E-01

Table A-4 -- Results of CDA simulation for Gilmore Creek

Earth station latitude = 64°59'
Total elapsed time = 216,000 minutes
Total reception/tracking time = 8,592 minutes
Total time of POMS mutual visibility = 1,396 minutes

C/I Range (dB)	Duration (min.)	Fraction of Total Visibility	Cumulative Fraction of Visibility
16.0 < C/I < 18.0	0.5	5.82E-05	5.82E-05
18.0 < C/I < 20.0	0.5	5.82E-05	1.16E-04
20.0 < C/I < 22.0	0.5	5.82E-05	1.75E-04
22.0 < C/I < 24.0	0.5	5.82E-05	2.33E-04
24.0 < C/I < 26.0	1.0	1.16E-04	3.49E-04
26.0 < C/I < 28.0	1.5	1.75E-04	5.24E-04
28.0 < C/I < 30.0	0.0	0.00E+00	5.24E-04
30.0 < C/I < 32.0	2.0	2.33E-04	7.57E-04
32.0 < C/I < 34.0	3.5	4.07E-04	1.16E-03
34.0 < C/I < 36.0	3.5	4.07E-04	1.57E-03
36.0 < C/I < 38.0	10.0	1.16E-03	2.74E-03
38.0 < C/I < 40.0	8.0	9.31E-04	3.67E-03
40.0 < C/I < 42.0	14.0	1.63E-03	5.30E-03
42.0 < C/I < 44.0	20.0	2.33E-03	7.62E-03
44.0 < C/I < 46.0	29.0	3.38E-03	1.10E-02
46.0 < C/I < 48.0	28.0	3.26E-03	1.43E-02
48.0 < C/I < 50.0	45.0	5.24E-03	1.95E-02
50.0 < C/I < 52.0	80.5	9.37E-03	2.89E-02
52.0 < C/I < 54.0	132.5	1.54E-02	4.43E-02
54.0 < C/I < 56.0	215.0	2.50E-02	6.93E-02
56.0 < C/I < 58.0	308.5	3.59E-02	1.05E-01
58.0 < C/I < 60.0	267.5	3.11E-02	1.36E-01
60.0 < C/I < 62.0	152.0	1.77E-02	1.54E-01
62.0 < C/I < 64.0	60.0	6.98E-03	1.61E-01
64.0 < C/I < 66.0	12.5	1.45E-03	1.62E-01
66.0 < C/I < 68.0	0.0	0.00E+00	1.62E-01
68.0 < C/I < ∞	0.0	0.00E+00	1.62E-01

APPENDIX B - ANALYSIS OF FREQUENCY SHARING WITH SYSTEMS IN THE FIXED-SATELLITE SERVICE OPERATING IN THE BAND 7450-7550 MHz

B.1 Introduction

The 7450-7550 MHz band is extensively utilized by the systems in the Fixed-Satellite Service (FSS) for downlinks from satellites in geostationary orbit. These FSS systems could cause or suffer interference with respect to post-NOAA-M CDA systems. This appendix establishes a method for identifying FSS earth stations that may be affected by the sharing, analyzes the general frequency sharing situation, and shows that interference between the CDA and FSS systems will be at acceptable levels without extraordinary CDA downlink operating or design constraints.

B.2 Stations That May Be Affected

CDA stations are generally located at latitudes at least 35° from the equator because the satellite (generally at altitudes of 600-1000 km) is more frequently in view from higher latitudes. These stations will operate at the current Wallops Island, VA, and Gilmore Creek, AL, sites; a third station may be operated at Tromso, Norway. The CDA station location serves as a convenient reference point for identifying potentially affected FSS earth stations and their associated satellites since the transmitter on board the Metsat satellite is only activated when in view of the CDA station at elevation angles greater than a certain minimum value. (Minimum elevation angle constraints are established by the physical constraints imposed by pointing large, heavy CDA antennas and the intra-system degradations suffered on the obstructed or relatively long paths to the satellite at low elevation angles.)

B.2.1 Geostationary Orbital Locations of FSS Satellites That Could Potentially Affect a METSAT Earth Station

The identification of FSS satellites in geostationary orbit that could cause interference to a METSAT earth station is accomplished by determining the portion of the geostationary orbit visible from the METSAT earth station above a specified minimum elevation angle. The International Frequency Registration Board (IFRB) Advanced Publications and Notifications can then be reviewed to identify the particular satellites that are situated in the calculated arc. This arc extends by a certain angle, $\pm\beta$, from the longitude of the METSAT earth station and may be calculated as follows:

$$\beta = \text{arc cos}\left[\frac{[1 - (D/42,644)]^2}{0.2954 \cdot \cos\Gamma}\right] \qquad (1)$$

$$D = (R_e+h)\left[\frac{\sin(90-E-\arcsin[(Re/Re+h)\cos E])}{\cos E}\right] \quad \text{km} \qquad (2)$$

where:

β = maximum difference in longitude between a visible FSS satellite and the METSAT earth station;

Γ = latitude of the METSAT earth station;

D = slant range (km) between the FSS satellite and METSAT earth station;

R_e = radius of earth (km), (6378 km);

h = altitude (km) of the FSS satellite (35,788 km);

E = elevation angle (degrees) measured at the METSAT earth station towards the most easterly or westerly positions in the visible portion of the geostationary orbit (i.e., the elevation angle of the terrain in that direction).

Using the example of a CDA station located at 75.5° longitude and 37.95° latitude, with physical horizon angles of 0° towards the most easterly and westerly visible points in the geostationary orbit, the arc can be determined as follows (starting with Equation 2):

$$D = (6378+35788)\left[\frac{\sin(90-0-\arcsin[(6378/6378+35788)\cos 0])}{\cos 0}\right]$$

D = 41680 km

Therefore, Equation 1 gives β = 72.6° to both the east and west and the geostationary orbit arc containing FSS satellites that could affect the example CDA station extends over 2β or 145.2°, at longitudes from 148.1° W to 2.9° W.

B.2.2 Locations of FSS earth stations that might be affected

The area within a circle centered on the METSAT earth station may be used to define the locations where interference to FSS earth stations might be caused by emissions from METSAT satellites. The radius of this circle is determined by the distance between the CDA station and any FSS earth station that may be visible to the METSAT spacecraft while it is transmitting to the CDA earth station. The radius S of the circle containing all potentially affected FSS earth stations is determined from the following equations:

$$S = S_{MET} + S_{FSS} \tag{3}$$

where:

S = maximum surface distance (km) between a CDA earth station and an FSS earth station which could receive interference;

S_{MET} = maximum surface (km) distance from the subsatellite point to a CDA earth station receiving transmissions from the METSAT spacecraft (km);

S_{FSS} = maximum surface distance (km) at which an FSS earth station could be visible to a METSAT spacecraft.

with:

$$S_{MET} \text{ or } S_{FSS} = 2\pi \cdot R_e \cdot [(90 - E + \phi) \div 360] \tag{4}$$

$$\phi = \text{arc sin } [(R_e \cdot \sin 90 + E\ ) \div (h + R_e)] \tag{5}$$

where:

ϕ = exocentric angle (degrees) at the METSAT satellite from nadir to the Earth horizon;

R_e = radius of the Earth (6378 km);

E = elevation angle (degrees) towards the METSAT satellite;

h = altitude (km) of the METSAT satellite.

For example, assuming a minimum operational elevation angle of 5° for the METSAT earth station antenna and an 825 km orbital altitude for the METSAT satellite, then the distance between the earth station and the farthest subsatellite point during transmission is:

$$\phi = \text{arc sin } [(6378 \cdot \sin 90 + 5) \div (825 + 6378)] = 61.9°$$

$$S_{MET} = 2\pi(6378)[23.1/360] = 2572 \text{ km}$$

An elevation angle of 0° at the FSS earth station towards the METSAT satellite at the above position similarly determines a distance of 3158 km between the FSS earth station and the subsatellite point. Thus, FSS earth stations located within an area of (2572 km + 3158 km = 5730 km) radius centered on the CDA earth station could be affected by METSAT downlink transmissions.

B.3 Analysis of the general sharing situation

An analysis was conducted of the interference between example METSAT and FSS systems to determine the statistics of interference. This section describes the assumed sharing scenarios and the analytical approach, and discusses the analysis results.

B.3.1 Assumed sharing scenarios

Advance Publications and Notifications (as of November 1988) for FSS systems that may be operating downlinks in the band 7450-7550 MHz were reviewed to determine representative FSS system characteristics. About 50 satellites were identified, with an average deployment density of about one satellite per seven degrees of orbital arc and a peak density within a forty degree arc of about one satellite per 3.5°. It was assumed for the analysis of FSS satellite constellations that satellites are uniformly spaced by three degrees in order to account for potential future growth. Table B-1 presents a summary of other relevant characteristics for FSS systems using small earth station antennas and the satellite e.i.r.p. levels assumed in the analysis. The FSS earth station antennas are assumed to have the radiation pattern given in Appendix 29 to the Radio Regulations.

TABLE B-1 -- FSS system parameters used in analysis

Earth Station Antenna Diameter (meters)	Satellite Parameters			
	Minimum e.i.r.p. (dBW/Hz)	Maximum e.i.r.p. (dBW/Hz)	Assumed e.i.r.p. (dBW/Hz)	Transmission Bandwidth (kHz)
1.00	-30	-25	-27	<85,000
2.44	-38	-26	-32	<85,000
6.09	-38	-24	-31	<85,000

The parameters assumed for the METSAT system are based on the system described in Section 4 and are listed below.

- METSAT Earth Station
  - Latitudes: 35°N, 50°N, 65°N.
  - Frequency: 7500 GHz.
  - Antenna diameter: 25.9 meters; gain of 64.8 dBi; antenna off-axis gain pattern of Appendix 29 of the Radio Regulations.
  - Minimum elevation angle for METSAT transmission and reception: 5 degrees above smooth Earth horizon.
  - Minimum satellite visibility time (above 5 degree elevation angle) for which data retrieval is attempted: 0 seconds (worst-case assumption regarding transmission scheduling).

o METSAT Satellite

- Sun synchronous, circular orbit.
- Orbital height: 825 kilometers above earth surface.
- Orbital inclination: 98.89 degrees.
- Satellite antenna input power: 16 dBW/100 MHz, (power density of -62 dBW/Hz).
- Satellite antenna gain: 2.1 dBi towards Earth limb, decreasing to -4.5 dBi at nadir.
- Satellite transmits only when commanded by a METSAT earth station.

The deployment scenarios and other factors were assumed to be as follows:

o FSS satellite location(s), three variations

(1) A single satellite located as far east as visible at the five degree minimum operational elevation angle of the CDA station. (See Table II, which summarizes the relative positions of the METSAT earth station, the FSS earth station, and the FSS satellite.)

(2) A single satellite located at the same longitude as the METSAT earth station.

(3) A constellation of FSS satellites spaced every 3 degrees (used only with the METSAT earth station as the victim receiver).

o FSS satellite antenna gain: no allowance for off-axis discrimination towards the victim METSAT earth station.

o FSS Earth Station Location: Worst case (i.e., positioned for maximum cumulative time of visibility to the METSAT satellite). Positioned 512 km (4.6 degrees of spherical arc distance) to the north-west of the METSAT earth station, in the plane defined by the Earth center and the position of the FSS satellite whose transmissions are being received and the METSAT earth station. The relative positions of the METSAT and FSS earth stations and the FSS satellite are summarized in Table B-2. (It should be noted that at other locations, FSS earth stations would receive significantly lower levels of interference with a given probability).

TABLE B-2 -- Geometrical Parameters Used in Analysis

METSAT EARTH STATION LAT. (deg.)	FSS SAT. LONG. (deg.)	FSS SAT. WITH RESPECT TO METSAT EARTH STATION ELEV (deg.)	AZIMUTH (deg.)	FSS EARTH STATION LOCATION LAT. (deg.)	LONG. (deg.)	FSS SAT. WITH RESPECT TO FSS EARTH STATION ELEV (deg.)	AZIMUTH (deg.)
35N	073.2E	05.0	100	35.7N	005.6W	00.4	097
50N	068.4E	05.0	107	51.1N	007.0W	00.4	101
65N	056.0E	05.0	121	67.1N	010.1W	00.4	112
35N	000.0E	49.3	180	39.6N	000.0E	44.2	180
50N	000.0E	32.7	180	54.6N	000.0E	27.7	180
65N	000.0E	16.7	180	69.6N	000.0E	11.9	180

B.3.2 Analytical Approach

The carrier-to-interference power density ratio C_o/I_o was computed and recorded for the FSS and METSAT earth stations in a simulation program as the METSAT satellite orbited the Earth. The simulations were terminated when the statistics of the C_o/I_o stabilized and reached asymptotic values. The C_o/I_o approach was used because it yields worst-case results which could later be adjusted to estimate C/I values on the basis of emission bandwidths, modulation types, and the number FSS carriers within the 100 MHz reference bandwidth of the METSAT receiver.

B.3.3 Discussion of Results

Figure B-1 presents the results of the analysis of interference to the METSAT earth station from a single FSS satellite and from the constellation of FSS satellites. Figure B-2 present the results for interference to FSS earth stations located at sites experiencing the highest levels of interference. Comparisons of the results for the METSAT and FSS systems show that the METSAT system will generally experience significantly lower C_o/I_o values than the FSS systems.

B.3.3.1 Interference at METSAT Earth Stations

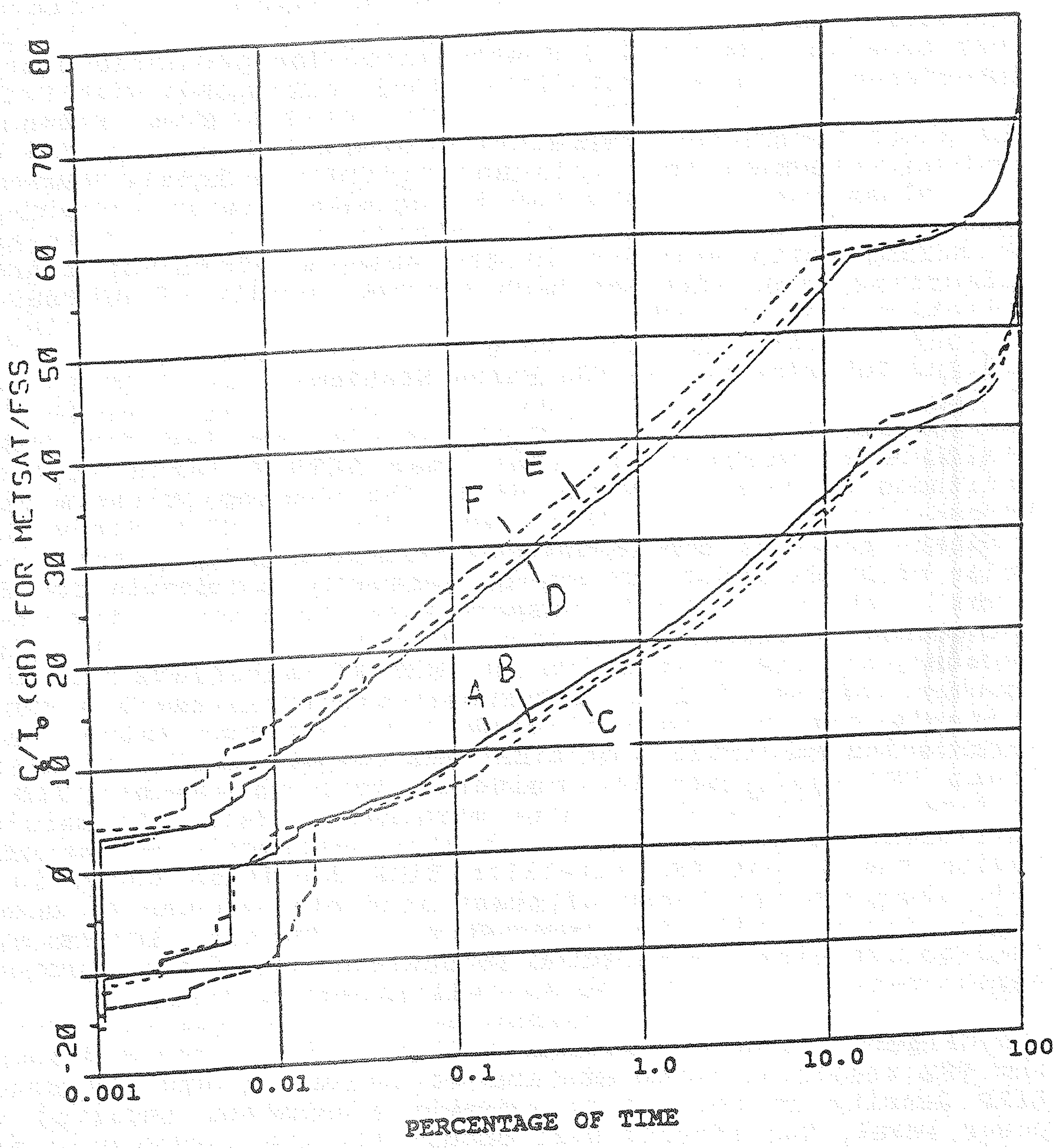
Figure B-1 shows that the an FSS satellite could cause C_o/I_o values of about 5 dB at a METSAT earth station for percentages of time on the order of 0.003% and about 57 dB for percentages of time on the order of 20%. The applicable single-entry sharing criteria given in [17] for the assumed METSAT system are C/Is of 12 dB and 33.7 dB for 0.0038% and 20% of the time, respectively. The actual C/I at the METSAT receiver will be significantly greater than the the C_o/I_o values shown in Figure 1, because there are guardbands between the FSS carriers and the assumed FSS satellite power densities values are greater than those used throughout many FSS carriers. Thus, there is not likely to be a need to schedule METSAT transmissions for the protection of the METSAT receiver from the emissions of individual FSS satellites.

Figure B-1 also shows that the aggregate interference from a constellation of FSS satellites is more than 10 dB higher than that from an individual FSS satellite. The permissible aggregate interference from all satellites [16] corresponds with C/Is of 12 dB and 27.3 dB for 0.01875% and 20% of the time, respectively. The short term interference criteria are not met for the example systems, assuming that C/Is and C_o/I_os are equal. However, the C/I values could be expected to be much higher than the C_o/I_o values, such that unacceptable interference would not be expected at METSAT earth stations in the absence of METSAT tranmission scheduling, even with the high assumed density of FSS satellites operating near 7500 MHz.

B.3.3.2 Interference at FSS Earth Stations

Figure B-2 shows the C_o/I_o levels computed for FSS earth stations at worst-case sites near METSAT earth stations at latitudes of 35°N, 50°N and 65°N. The sharing criteria given in Recommendations 466-2, 483-1 and 523-2 of CCIR Study Group 4 indicate that for single-entry interference, C_o/I_o values on the order of 28 dB and 21 dB may be generally acceptable for 20% and 0.03% of the worst month, respectively. Note that interference is not possible for more than about 8.5% of the time at any latitude because of the statistics of METSAT satellite visibility; however, values of C_o/I_o interpolated between the 20% and 0.03% criteria can be compared with the computed values for the intervening percentages of time. The computed C_o/I_o values exceed these FSS C_o/I_o sharing criteria for the assumed FSS earth stations in all cases by large margins. In fact, the margins are sufficient to protect FSS earth stations receiving the carriers having the lowest FSS satellite EIRP densities shown in Table B-1. Thus, on the basis of these findings, it can be seen that METSAT systems with the assumed satellite EIRP levels may not need to practice transmission scheduling in order to protect FSS earth stations operating with small antennas.

Figure B-2 also illustrates that as the antenna diameter of the FSS receiving earth station is increased, and its satellite EIRP density is reduced to provide a constant received signal power level, two effects will occur: (1) the assymptotic minimum value of C_o/I_o will decrease with the FSS satellite EIRP, but (2) the C_o/I_o value exceeded for 0.03% and greater percentages of the time will increase. The latter effect is a result of the reduction of earth station antenna beamwidth with increasing antenna diameter (and gain), which decreases the percentages of time during which the C_o/I_o level is near the assymptotic minimum C_o/I_o value. Thus, interference to FSS earth stations having larger antennas than those assumed in this analysis may also be at acceptable levels in the absence of METSAT transmission scheduling. Further analysis of typical FSS downlinks to large FSS earth stations is needed to confirm this deduction.

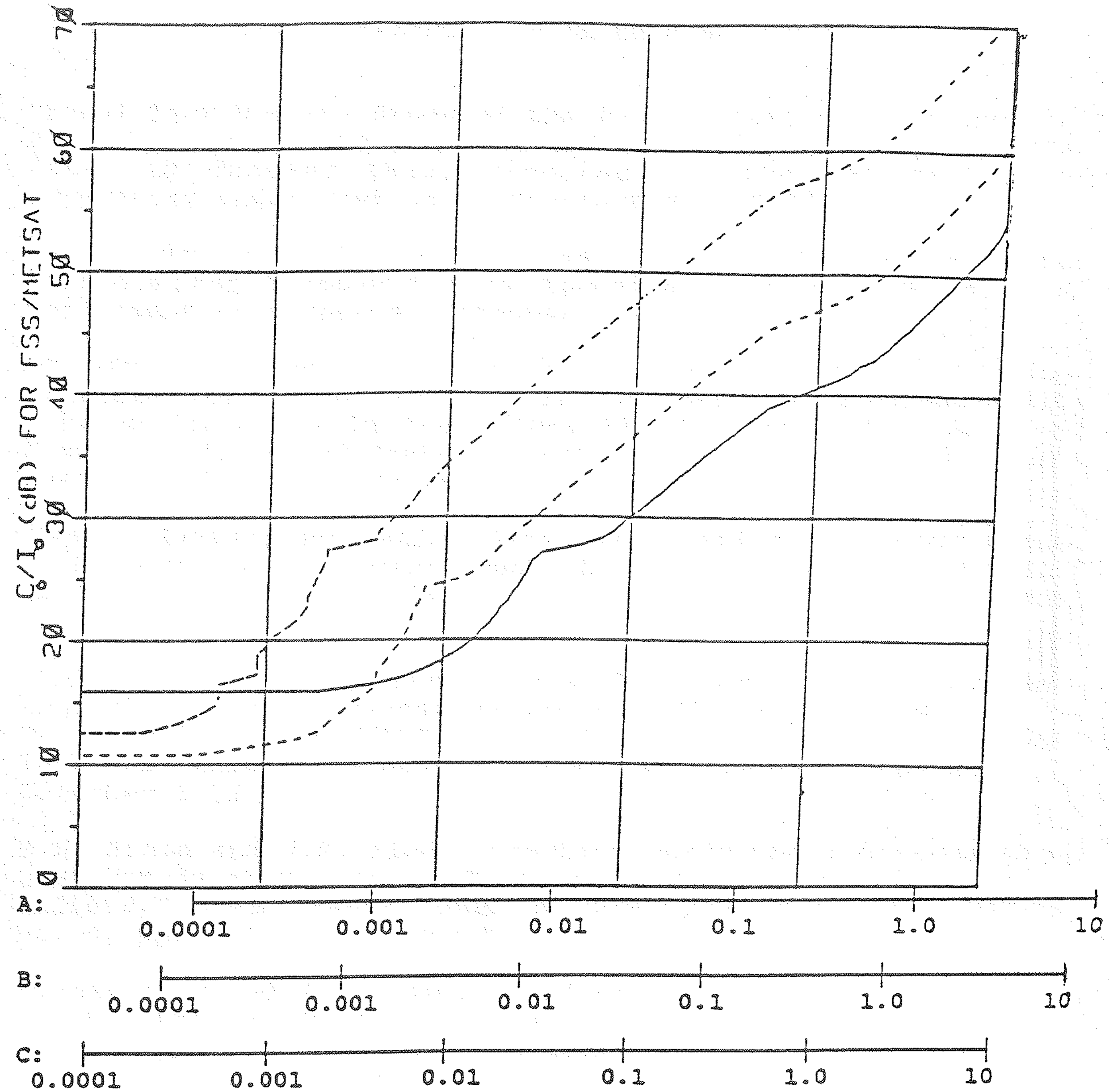


<u>Legend</u>

A: METSAT earth station at 35°N, 53 FSS satellites interfering
B: METSAT earth station at 50°N, 51 FSS satellites interfering
C: METSAT earth station at 65°N, 46 FSS satellites interfering

D: METSAT earth station at 35°N, one FSS satellite interfering
E: METSAT earth station at 50°N, one FSS satellite interfering
F: METSAT earth station at 65°N, one FSS satellite interfering

Figure B-1. Carrier-to-interferences power densities calculated for METSAT earth station receivers



<u>Legend</u>

——————— : FSS earth station with 1.0 meter antenna
– – – – – – : FSS earth station with 2.44 meter antenna
–·–·–·–·– : FSS earth station with 6.09 meter antenna
Scale A: METSAT earth station at 35°N latitude
Scale B: METSAT earth station at 50°N latitude
Scale C: METSAT earth station at 65°N latitude

Figure B-2. Carrier-to-interferences power densities calculated for FSS earth station receivers at the worst-case site with respect to a METSAT earth station at 35°N latitude.

APPENDIX C - REFERENCES

1. "Final Task Report, Study of the Implementation of an Advanced HRPT Service in the Mid-1990's," ORI Technical Report 2804, dated 29 January 1988, Prepared for the Jet Propulsion Laboratory under Task 15 to Contract No. 957262.

2. J.R. Schneider, "Guide for Designing RF Ground Receiving Stations for Tiros-N," NOAA Technical Report NESS 75, U.S. Department of Commerce, December 1976.

3. "Draft New Report, Performance, Interference and Sharing Criteria for Earth Stations in the Meteorological-Satellite Service Operating in the 1670-1700 MHz Band," Doc. 2/34, 12 August 1987, United States contribution to the Interim Meetings of CCIR Study Group 2.

4. "Space Radiocommunication Services, Sharing Frequency Bands with Terrestrial Radiocommunication Services Above 1 GHz," Article 28, Radio Regulations, Edition of 1982, International Telecommunication Union, Geneva, Switzerland

5. J.H. Yuen, editor, Deep Space Telecommunications Systems Engineering, JPL Publication 82-76, 1982, pp. 183-189.

6. A. Schwalb, "The TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS 95, U.S. Department of Commerce, December 1982

7. M.K. Simon and W.K. Alem, "Tracking Performance of Unbalanced QPSK Demodulators: Part I-Biphase Costas Loop with Passive Arm Filters," IEEE Transactions on Communications, Vol. COM-26, No. 8, pp. 1147-1156, August 1978.

8. D. Divsalar and J.H. Yuen, "Performance of Unbalanced QPSK in the Presence of Noisy Reference and Crosstalk," NTC Conference Record, pp. 44.4.1-44.4.7, November 1979.

9. R.D. Cideciyan, J.J.M. Wang, and W.C. Lindsey, "False Lock in Quadriphase Receivers with Unequal I- and Q-Channel Data Rates," IEEE Transactions on Communications, Vol. COM-37, No. 2, pp. 152-158, February 1989.

10. People's Republic of China, Information Supplied for Advance Publication for the FY-1 Satellite Network," IFRB Weekly Circular No. 1764, March 10, 1987.

11. CCIR, "Performance, Interference and Sharing Criteria for Receiving Earth Stations in the Meteorological-Satellite Service Operating in the 1670-1710 MHz Band With Satellites in Low Earth Orbit," Report AC/2, Conclusions of the Interim Meeting of Study Group 2, Doc. 2/107, February 25, 1988 [as modified by U.S. draft Doc. USSG 2E-1, March 28, 1989].

12. "Frequency Allocations," Article 8, Radio Regulations, Edition of 1982, International Telecommunication Union, Geneva, Switzerland

13. Interface Specification, TIROS-N Satellite - Ground System, IS-2285557, RCA Astro-Electronics Division (as revised through April 20, 1982).

14. CCIR, "Interference Protection Criteria for the Radio Astronomy Service," Report 224-6, Geneva, 1986.

15. Locke, P. and Rinker, A., "The Low Orbit Satellites and Interference Model," Telecommunication Journal, Vol. 45, pp 229-237, 1978.

16. United States CCIR Study Group 2, "Performance, Interference and Sharing Criteria for Receiving Earth Stations in the Meteorological-Satellite Service Operating in the 7450-7550 MHz Band With Satellites in Low Earth Orbit," Doc. USSG 2E-2, March 28, 1989 [for submission to 1989 CCIR Final Meeting].

U.S.GOVERNMENT PRINTING OFFICE:1989-242-202/00022

(Continued from inside front cover)

NESDIS 16 Temporal and Spatial Analyses of Civil Marine Satellite Requirements. Nancy J. Hooper and John W. Sherman III, February 1985. (PB86 212123/AS)

NESDIS 17 reserved

NESDIS 18 Earth Observations and the Polar Platform. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 177624/AS)

NESDIS 19 The Space Station Polar Platform: Intergrating Research and Operational Missions. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 195279/AS)

NESDIS 20 An Atlas of High Altitude Aircraft Measured Radiance of White Sands, New Mexico, in the 450-1050nm Band. Gilbert R. Smith, Robert H. Levin and John S. Knoll, April 1985. (PB85 204501/AS)

NESDIS 21 High Altitude Measured Radiance of White Sands, New Mexico, in the 400-2000nm Band Using a Filter Wedge Spectrometer. Gilbert R. Smith and Robert H. Levin, April 1985. (PB85 206084/AS)

NESDIS 22 The Space Station Polar Platform: NOAA Systems Considerations and Requirements. John H. McElroy and Stanley R. Schneider, June 1985. (PB86 6109246/AS)

NESDIS 23 The Use of TOMS Data in Evaluating and Improving the Total Ozone from TOVS Measurements. James H. Lienesch and Prabhat K.K. Pandey, July 1985. (PB86 108412/AS)

NESDIS 24 Satellite-Derived Moisture Profiles. Andrew Timchalk, April 1986. (PB86 232923/AS)

NESDIS 25 reserved

NESDIS 26 Monthly and Seasonal Mean Outgoing Longwave Radiation and Anomalies. Arnold Gruber, Marylin Varnadore, Phillip A. Arkin, and Jay S. Winston, October 1987. (PB87160545/AS)

NESDIS 27 Estimation of Broadband Planetary Albedo from Operational Narrowband Satellite Measurements. James Wydick, April 1987. (PB88-107644/AS)

NESDIS 28 The AVHRR/HIRS Operational Method for Satellite Based Sea Surface Temperature Determination. Charles Walton, March 1987. (PB88-107594/AS)

NESDIS 29 The Complementary Roles of Microwave and Infrared Instruments in Atmospheric Sounding. Larry McMillin, February 1987. (PB87 184917/AS)

NESDIS 30 Planning for Future Generational Sensors and Other Priorities. James C. Fischer, June 1987. (PB87 220802/AS)

NESDIS 31 Data Processing Algorithms for Inferring Stratospheric Gas Concentrations from Balloon-Based Solar Occultation Data. I-Lok Chang (American University) and Michael P. Weinreb, April 1987. (PB87 196424)

NESDIS 32 Precipitation Detection with Satellite Microwave Data. Yang Chenggang and Andrew Timchalk, June 1988. (PB88-240239)

NESDIS 33 An Introduction to the GOES I-M Imager and Sounder Instruments and the GVAR Retransmission Format. Raymond J. Komajda (Mitre Corp) and Keith McKenzie, October 1987. (PB88-132709)

NESDIS 34 Balloon-Based Infrared Solar Occultation Measurements of Stratospheric O3, H2O, HNo3, and CF2Cl2. Michael P. Weinreb and I-Lok Chang (American University), September 1987. (PB88-132725)

NESDIS 35 Passive Microwave Observing From Environmental Satellites, A Status Report Based on NOAA's June 1-4, 1987, Conference in Williamsburg, Virginia. James C. Fischer, November 1987. (PB88-208236).

NESDIS 36 Pre-Launch Calibration of Channels 1 and 2 of the Advanced Very High Resolution Radiometer. C.R. Nagaraja Rao, October 1987. (PB88-157169 A/S)

NESDIS 39 General Determination of Earth Surface Type and Cloud Amount Using Multispectral AVHRR Data. Irwin Ruff and Arnold Gruber, February 1988. (PB88-199195/AS)

NESDIS 40 The GOES I-M System Functional Description. Carolyn Bradley (Mitre Corp), November 1988.

NESDIS 41 Report of the Earth Radiation Budget Requirements Review - 1987 Rosslyn, Virginia, 30 March - 3 April 1987. L.L. Stowe (Editor), June 1988.

NESDIS 42 Simulation Studies of Improved Sounding Systems. H. Yates, D. Wark, H. Aumann, N. Evans, N. Phillips, J. Sussking, L. McMillin, A. Goldman, M. Chahine, and L. Crone, February 1989.

NESDIS 43 Adjustment of Microwave Spectral Radiances of the Earth to a Fixed Angle of Progagation. D. Q. Wark, December 1988. (PB89-162556/AS)

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS—Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS—Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS—Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS—Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS—Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS—Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
Washington, D.C. 20233